

Theoretical investigation of the decay of the $N(2120)$ resonance to nucleon resonances near 1.7 GeV

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Background: Until now the knowledge about nucleon resonances with a mass higher than 2 GeV has been scarce. Huge amounts of experimental data of the multipion photoproduction have been accumulated, and more can be expected in the future in facilities such as JLab 12 GeV. It makes it possible to investigate the decay of a nucleon resonance into another nucleon resonance.

Purpose: The possibility to research the decay of the $N(2120)$ to nucleon resonances near 1.7 GeV in the three-pion photoproduction will be explored to provide useful information for future experimental study.

Method: The pion and radiative decay amplitudes of nucleon resonances are studied within the constituent quark model, which is used to calculate the couplings constants, especially for the decay of a nucleon resonance near 2.1 GeV to another nucleon resonance near 1.7 GeV. The three-pion photoproduction off the neutron target, i.e., $\gamma n \rightarrow \pi^- \pi^- \Delta^{++} \rightarrow \pi^- \pi^- \pi^+ p$, is investigated based on the effective Lagrangian method with the coupling constant obtained from the decay amplitudes.

Results: The resonance contribution with a state $N(2P_M)\frac{3}{2}^-$ near 2.1 GeV decaying to a state $N(4P_M)\frac{5}{2}^-$ near 1.7 GeV, i. e., $N(2120) \rightarrow N(1675)\pi$ is dominant in the process considered. The total cross section from the resonance contribution is at the order of $1 \mu\text{b}$ and can be easily distinguished from the background.

Conclusions: Our results suggest it is practicable to research the decay of the $N(2120)$ to the $N(1675)$ in experiment.

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I. INTRODUCTION

With improvement of experimental technique, the understanding about nucleon resonances has deepened in recent years. More nucleon resonances near 1.9 GeV were listed in the new version of the review of particle physics [Particle Data Group (PDG)] [1], which is a great progress about the long standing “missing resonances” problem. However, the knowledge about resonances with mass higher than 2 GeV are still scarce. The nucleon resonances observed is much less than those predicted in the constituent quark model. For the nucleon resonances observed, the internal structure is still in controversy. For example, based on the prediction in the constituent quark model [2, 3], a nucleon resonance near 2.1 GeV, which is the third $N3/2^-$ state, should play an important role in the $\Lambda(1520)$ photoproduction [4, 5]. However, Klemp claimed that the $N(1875)$ instead of $N(2120)$ is the missing third $N3/2^-$ state [6].

It was predicted in the constituent quark model that more nucleon resonances will be found in the higher mass region. For example, the number of $N = 2$ shell states is much larger than that of $N = 1$ shell states. It requires experimental data from more channels to distinguish the predicted nucleon resonances above 2 GeV. Currently most information about nucleon resonances is extracted from pion nucleon scattering and single meson photoproduction. A high-mass nucleon resonance is prone to decay into a baryon resonance with a me-

son, which provides a new way to detect internal structure of high-mass nucleon resonance. In recent years, a few attentions have been attracted by the decay of a nucleon resonances to a baryon resonance. For example, due to the high thresholds of the $\Lambda(1520)$ and $\Sigma(1385)$ photoproductions it was suggested by several authors that the new experimental data released by the CLAS Collaboration [7] are very useful to study a nucleon resonance near 2.1 GeV [4, 8, 9]. In order to analyze various isospin channels of double-pion production in nucleon-nucleon collisions, the contribution from $\Delta(1600)$ decaying to the Roper resonance $N(1440)$ in process $NN \rightarrow NN\pi\pi$ was mentioned [10]. However, up to now only the branch ratio of $\Delta(1600) \rightarrow \pi N(1440)$ has been provided by the PDG [1].

The two-pion and three-pion photoproductions have been measured in many facilities, such as CLAS@JLab and MAMI, and a large amount of data have been accumulated in recent years. Most analyses about these data aimed to study the light meson spectrum and to search for the exotic meson. Besides the light meson production with t channel exchange mechanism, if the photon carries enough energy the initial nucleon will be excited to a nucleon resonance with a mass higher than 2 GeV, then decay to a baryon resonance with lower mass. For example, the $\Lambda(1520)$ and $\Sigma(1385)$ photoproductions are extracted from multimeson photoproduction with nucleon [7]. The high energy and high intensity photon beam in the CLAS@JLab experiment provides an opportunity to study nucleon resonance in the high-mass range. In the future experiments at GlueX and CLAS12 detectors, more data will be collected, which makes it more feasible to study the decay of a nucleon resonance into another resonance.

One reaction of interest is $\gamma n \rightarrow \pi^- \pi^- \Delta^{++} \rightarrow \pi^- \pi^- \pi^+ p$, which is a typical three-pion photoproduction reaction. In

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data analysis it is easy to reconstruct Δ^{++} , so the two-pion production combined with a Δ^{++} instead of the full three-pion photoproduction will be considered in this work. Moreover, it is easy to detect in experiment due to the charged final particles. In this work, we will focus on the decay of a nucleon resonance near 2.1 GeV, especially the interesting $N(2120)$. According to the PDG [1], the resonances with large branch ratios in the $\Delta\pi$ channel concentrate around 1.7 GeV. Hence, the decays of nucleon resonances near 2.1 GeV to a nucleon resonance near 1.7 GeV are focused on in this work. The decay amplitudes will be studied in the constituent quark model. And the coupling constants for the radiative and strong decays will be calculated from the decay amplitudes. With the coupling constants obtained, the cross section of pion photoproduction off the neutron target with the Δ baryon, i.e., $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$, will be studied by using the effective Lagrangian method.

This article is organized as follows. The model used in this work is presented in the next section. The interaction mechanisms of $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ are presented and the possible backgrounds are also discussed. The coupling constants for pion decays of nucleon resonances are studied in the constituent quark model under $SU(6) \otimes O(3)$ symmetry. The numerical results are given in Sec. III. A brief summary is given in the last section.

II. MODEL

A. Interaction mechanism

The interaction mechanisms for the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ can be divided into two categories, namely, resonance contribution and background contribution. The resonance contribution, which is focused on in this work, includes mechanisms with the decay of a nucleon resonance to another nucleon resonance. As illustrated in Fig. 1, photon γ strikes on neutron n and excites it to a nucleon resonance R'^0 with higher mass, such as about 2.1 GeV. Then this nucleon resonance R'^0 decays to a lower resonance R^+ , which decays to Δ^{++} with a pion meson finally.

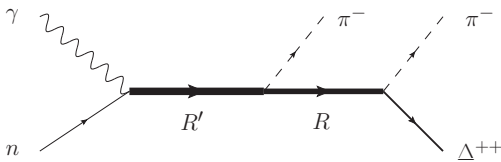


FIG. 1: Feynman diagrams for the resonance contribution of $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ reaction.

To calculate the amplitudes of these diagrams, it is essential to know the Lagrangians for a vertex for excitation of neutron to nucleon resonance R'^0 , a vertex for pion decay of a nucleon resonance R'^0 to R^+ and a vertex for pion decay of a nucleon resonance to Δ^{++} . Such Lagrangians have been constructed

in Refs. [11–13] for the resonances with arbitrary half-integer spin, which are in the forms of

$$\mathcal{L}_{\gamma NR[\frac{1}{2}^{\pm}]} = \frac{ef_2}{2M_N} \bar{N} \Gamma^{(\mp)} \sigma_{\mu\nu} F^{\mu\nu} R + \text{H.c.}, \quad (1)$$

$$\begin{aligned} \mathcal{L}_{\gamma NR[J^{\pm}]} &= \frac{-i^n f_1}{(2m_N)^n} \bar{N}^* \gamma_\nu \partial_{\mu_2} \dots \partial_{\mu_n} F_{\mu_1 \nu} \Gamma^{\pm(-1)^{n+1}} R^{\mu_1 \mu_2 \dots \mu_n} \\ &+ \frac{i^{n+1} f_2}{(2m_N)^{n+1}} \partial_\nu \bar{N} \partial_{\mu_2} \dots \partial_{\mu_n} F_{\mu_1 \nu} \Gamma^{\pm(-1)^{n+1}} R^{\mu_1 \mu_2 \dots \mu_n} \\ &+ \text{H.c.}, \end{aligned} \quad (2)$$

where $R^{\mu_1 \mu_2 \dots \mu_n}$ is the field for the resonance with spin $J = n + 1/2$, and $\Gamma^{(\pm)} = (i\gamma_5, 1)$ for the different resonance parities.

The Lagrangian for the strong decay can be written as

$$\mathcal{L}_{R'[\frac{1}{2}^{\pm}] \pi R[\frac{3}{2}^{\mp}]} = \frac{ig_2}{2M_\pi} \partial_\mu \pi \bar{R}'_1 \Gamma^{(\pm)} R + \text{H.c.}, \quad (3)$$

$$\begin{aligned} \mathcal{L}_{R'(J^{\pm}) \pi R[\frac{3}{2}^{\mp}]} &= \frac{i^{2-n} g_1}{(2m_\pi)^n} \bar{R}'_{1\mu_1}^* \gamma_\nu \partial_\nu \partial_{\mu_2} \dots \partial_{\mu_n} \pi \\ &\times \Gamma^{\pm(-1)^n} R^{\mu_1 \mu_2 \dots \mu_n} \\ &+ \frac{i^{1-n} g_2}{(2m_\pi)^{n+1}} \bar{R}'_{1\alpha}^* \partial_\alpha \partial_{\mu_1} \partial_{\mu_2} \dots \partial_{\mu_n} \pi \\ &\times \Gamma^{\pm(-1)^n} R^{\mu_1 \mu_2 \dots \mu_n} + \text{H.c.} \end{aligned} \quad (4)$$

The coupling constants will be calculated with the help of the constituent quark model in the next section. The isospin structure for $\Delta^* \pi N^*$ interaction reads

$$\begin{aligned} \bar{\Delta}^* \mathbf{T}_{\frac{3}{2}} \cdot \pi N^* &= (\sqrt{3} \pi^- \Delta^{*++} + \sqrt{2} \pi^0 \Delta^{*+} + \pi^+ \Delta^{*0}) N^{*+} \\ &+ \pi^- \Delta^{*+} N^{*0} + \sqrt{2} \pi^0 \Delta^{*0} N^{*0} + \sqrt{3} \pi^+ \Delta^{*0} N^{*-}. \end{aligned} \quad (5)$$

Besides the resonance contribution from cascade decay of nucleon resonance, there exist other interaction mechanisms, i. e., background contribution. In experiment, the two-pion production with t channel is often used to research the exotic meson. Fortunately, it is not involved in the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ because there does not exist a meson with charge $Q = -2$. The mechanisms in Figs. 2(a) and 2(b) with resonances R^+ are not considered in this work because the experimentist can remove such contributions based on the $\pi^- \Delta^{++}$ invariant mass spectrum. Hence, the background contribution is mainly from two mechanisms with proton p as shown in Fig. 2. The contact term is essential to keep the gauge invariance.

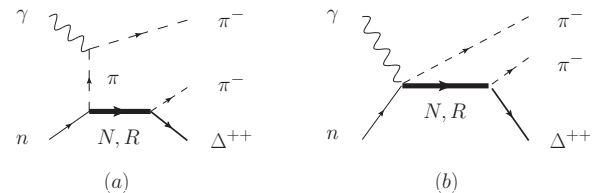


FIG. 2: Feynman diagrams of background contribution for $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ reaction. (a) t -channel, (b) contact term.

The interaction Lagrangians used in calculation of background contributions are [5, 14],

$$\begin{aligned}
\mathcal{L}_{\pi NN} &= -ig_{\pi NN}\bar{N}\gamma_5\gamma_\mu\tau\cdot\partial^\mu\pi N, \\
\mathcal{L}_{\pi N\Delta} &= \frac{g_{\pi N\Delta}}{m_\pi}\bar{N}\partial^\mu\pi\Delta_\mu, \\
\mathcal{L}_{\gamma NN} &= -e\bar{N}\left[Q_N A - \frac{\kappa_N}{4M_N}\sigma^{\mu\nu}F^{\mu\nu}\right]N, \\
\mathcal{L}_{\gamma\pi\pi} &= ie[(\partial^\mu\pi^\dagger)\pi - (\partial^\mu\pi)\pi^\dagger]A_\mu, \\
\mathcal{L}_{\gamma\pi NN} &= -\frac{ieQ_\pi g_{\pi NN}}{M_N}\bar{N}\gamma_5\tau\cdot\partial^\mu\pi A_\mu N,
\end{aligned} \tag{6}$$

where A^μ , π , N and Δ denote the fields for the photon, pion meson with mass m_π , nucleon with mass m_N and Δ , respectively. Here Q_h is the charge in the unit of $e = \sqrt{4\pi\alpha}$. The anomalous magnetic momentum of the neutron is $\kappa_n = -1.913$ [1]. The antisymmetric tensor is defined by $\sigma_{\mu\nu} = \frac{i}{2}(\gamma_{\mu\nu} - \gamma_{\nu\mu})$ and $F_{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$. The coupling constant of $g_{\pi N\Delta}$ can be obtained by the experimental decay width $\Gamma_{\Delta\rightarrow\pi N} = 116 - 120$ MeV [1] as $g_{\pi N\Delta} = 2.16 \pm 0.02$. The πNN coupling constant is chosen as $g_{\pi NN}^2/4\pi = 14.4$.

The form factor should be introduced to reflect the internal structure of hadrons. For the t -channel exchange in Fig. 2 (a), form factor has a form

$$F_\pi(t) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - t}, \tag{7}$$

where t is the square of the four-momentum of exchanged π meson. The cut off Λ_π is usually chosen close to 1 GeV. For the intermediate s channel the form factor is of the form

$$F(s) = \left(\frac{n\Lambda_{R,N}^4}{n\Lambda_{R,N}^4 + (s - M_{R,N}^2)^2} \right)^n, \tag{8}$$

where s is the square of the four-momentum of resonances and nucleon, and the parameter $n = 1$ or 2 for the nucleon or resonance intermediate s channel, respectively. The cut offs will be discussed in Sec. III B.

B. Decay of nucleon resonance in the constituent quark model

To calculate the resonance contribution it is necessary to determine the coupling constants for the decay of nucleon resonances in Eqs. (1)-(4). In Ref. [15] the coupling constants was related to the decay amplitudes and this method was applied in the studies about $\Lambda(1520)$ and $\Sigma(1385)$ photoproductions [4, 5, 8]. The decays of a nucleon resonance to a resonance has not been studied in the literature. In this work, the helicity amplitudes of radiative and strong decay amplitudes of nucleon resonances will be calculated within the constituent quark model following the method in Ref. [16].

The decay amplitudes is obtained by making a nonrelativistic reduction of quark-photon/meson interaction. The amplitudes are calculated by sandwiching this interaction between initial and final states under the $SU(6) \otimes O(3)$ symmetry. For

example, the definition of the helicity amplitude is as below,

$$A_\lambda = \frac{1}{\sqrt{2|k|}} \langle N, \lambda - 1 | -iH_\gamma | R, \lambda \rangle \tag{9}$$

where $|k| = (M_R^2 - M_n^2)/(2M_R)$ with k being the momentum of photon in the center of mass system of the decaying nucleon resonance, with M_R and M_n being the masses of resonance and neutron and $\lambda = 1/2$ or $3/2$ being the helicity. The explicit form of the interaction and decay amplitude for meson emission have been given explicitly in Ref. [16].

Here we adopt a non-relativistic constituent quark model to calculate decay amplitudes. Although this approach results in some loss of "model" accuracy, the non-relativistic constituent quark model can provide a general description of the hadron spectroscopy, which is enough in the current work. In Ref. [17], it has been found that for light-quark mesons and baryons, the relativistic quark potential model supports the non-relativistic calculations in general.

With the radiative and strong decay amplitudes obtained the coupling constants f_1 , f_2 , g_1 and g_2 are determined by the method following Refs. [4, 5, 8, 15]. Since there are two amplitudes $A_{1/2}$ and $A_{3/2}$ for the resonances with $J > 1/2$, the coupling constants f_1 and f_2 in $\mathcal{L}_{R\pi\gamma}$ can be extracted from the helicity amplitudes of the resonance R , $A_{1/2}'$ and $A_{3/2}'$. The amplitudes for a state with $J^P = 3/2^-$ reads,

$$A_{1/2}' = \frac{e\sqrt{6}}{12} \sqrt{\frac{|k|}{M_n M_R}} \left[f_1 + \frac{f_2}{4M_n^2} M_R(M_R + M_n) \right], \tag{10}$$

$$A_{3/2}' = \frac{e\sqrt{2}}{4M_n} \sqrt{\frac{|k|M_R}{M_n}} \left[f_1 + \frac{f_2}{4M_n} (M_R + M_n) \right]. \tag{11}$$

The coupling constants g_1 and g_2 can be calculated analogously. For the nucleon resonances with $J^P = 3/2^-$ decaying to a state with $J^P = 5/2^-$ with a pion, the decay amplitudes have a form,

$$A_{3/2}^\pi = -\frac{\sqrt{3}g_1}{(2M_\pi)^2} \mathcal{BF}, \tag{12}$$

$$\begin{aligned}
A_{1/2}^\pi &= -\frac{g_1}{\sqrt{2}(2M_\pi)^2} \left(\frac{2|p_\pi|^2}{M_R(M_R + E_R)} + 3 \right) \mathcal{BF} \\
&+ \frac{\sqrt{2}g_2}{(2M_\pi)^3} \frac{|p_\pi|(E_R + M_R)}{\sqrt{5M_R(E_R + M_R)}} \mathcal{B}^2,
\end{aligned} \tag{13}$$

where $\mathcal{B} = \left(\frac{E_\pi}{M_R} + \frac{|p_\pi|^2}{M_R(M_R + E_R)} + 1 \right) |p_\pi|$ and $\mathcal{F} = \frac{E_\pi(E_R + M_R) + |p_\pi|^2}{\sqrt{5M_R(E_R + M_R)}}$ with p_π and E_π being momentum and energy of π^- . M_R and E_R are mass and energy for a resonance R , respectively.

For a nucleon resonance with $5/2^-$ decaying to $\Delta\pi$, we have

$$A_{3/2}^\pi = \frac{i\sqrt{3}g_1}{(2M_\pi)^2} \mathcal{D}, \tag{14}$$

$$\begin{aligned}
A_{1/2}^\pi &= \frac{ig_1}{\sqrt{2}(2M_\pi)^2} \left(\frac{2|p_\pi|^2}{M_\Delta(M_\Delta + E_\Delta)} + 1 \right) \mathcal{D} \\
&+ \frac{i\sqrt{2}g_2}{(2M_\pi)^3} \frac{|p_\pi|^3}{\sqrt{5M_\Delta(E_\Delta + M_\Delta)}} \mathcal{B}',
\end{aligned} \tag{15}$$

where $\mathcal{B}' = \left(\frac{E_\pi}{M_\Delta} + \frac{|p_\pi|^2}{M_\Delta(M_\Delta + E_\Delta)} + 1 \right) |p_\pi|$ and $\mathcal{D} = \frac{(E_\Delta + M_\Delta + E_\pi)}{\sqrt{5M_\Delta(E_\Delta + M_\Delta)}} |p_\pi|^2$. M_Δ and E_Δ are mass and energy for Δ , respectively.

III. RESULTS

The decays of nucleon resonance R' near 2.1 GeV to nucleon resonance R near 1.7 GeV are focused on in the current work. The radiative decay widths for $R'^0 \rightarrow n\gamma$ and the strong decay widths for $R^+ \rightarrow \pi^- \Delta^{++}$ can be used to preliminarily select the nucleon resonances R and R' which are important in the resonance contribution. With the dominant channels selected, the cross sections of process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ will be calculated and the possibility of the experimental study will be discussed.

A. Decay amplitudes and coupling constants

The numerical results of helicity amplitudes for radiative and pion decays are listed in Tables I and II and the values suggested for three or four star resonances listed in the PDG are also presented for comparison. The resonances, which are not in the mass range concerned in this work, are excluded based on Ref. [18]. The state under $SU(6) \otimes O(3)$ in constituent quark model is labeled by the notation $X^{(2S+1)L_\pi} J^P$ in which $X = N$ or Δ , S is the quark total spin, L is the orbital angular momentum, π is the permutational symmetry (symmetric, mixed, antisymmetric) of the spatial wave function, and J^P is the total angular momentum and parity of the state.

One can find that the values obtained in the constituent quark model without mixing effect are comparable with the suggested values by the PDG [1]. Among the resonances near 2.1 GeV, the radiative decay widths of states $N(4P_M)_{\frac{3}{2}}^-$, $N(2P_M)_{\frac{3}{2}}^-$ and $\Delta(2P_M)_{\frac{3}{2}}^-$ are much larger than the decay widths of other resonances. And among the resonances near 1.7 GeV, state $N(4P_M)_{\frac{1}{2}}^-$, which corresponds to the $N(1650)$, and state $N(4P_M)_{\frac{5}{2}}^-$, which corresponds to the $N(1675)$, have relatively large decay width in $\pi^- \Delta^{++}$ channel.

The helicity amplitudes for $R'^0 \rightarrow R^+ \pi^-$ can be calculated analogously, which are tabulated in Table III. Here only the nucleon resonances selected in the above step are considered. In the channel $N(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{5}{2}}^- \pi^-$, a much large decay width can be found, which is expected to dominate in the total process.

Based on the analysis above, two channels $\gamma n \rightarrow N(4P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{1}{2}}^- \pi^- \rightarrow \Delta^{++} \pi^- \pi^-$ and $\gamma n \rightarrow N(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{5}{2}}^- \pi^- \rightarrow \Delta^{++} \pi^- \pi^-$ will be considered in the calculation of the cross section and larger contributions are expected from the later channel. The coupling constants f_1 and f_2 for radiative decay and g_1 and g_2 for π^- decay can be calculated with the formalism given in the previous section. The explicit values of the coupling constants for the selected channels are listed in Table IV. As shown in Eq.(3), there is

TABLE I: The amplitudes and decay width for $R'^0 \rightarrow n\gamma$. The experimental values are given under the theoretical values for three or four star resonances listed by the PDG [1].

State	$A_{3/2}^\pi$ [GeV $^{-1/2}$]	$A_{1/2}^\pi$ [GeV $^{-1/2}$]	Γ [MeV]
$N(4D_M)_{\frac{7}{2}}^+$	-0.023	-0.018	0.020
$N(2P_M)_{\frac{3}{2}}^-$	-i0.057	i0.015	0.180
$N(4P_M)_{\frac{3}{2}}^-$	i0.079	i0.015	0.328
$N(4D_M)_{\frac{3}{2}}^+$	0.018	-0.010	0.002
$N(1900)$	-0.010 ± 0.004	-0.011 ± 0.007	
$N(4P_M)_{\frac{5}{2}}^-$	-i0.063	-i0.045	0.080
$\Delta(4D_S)_{\frac{7}{2}}^+$	-0.045	-0.035	0.071
$\Delta(1950)$	-0.076 ± 0.012	-0.097 ± 0.010	
$\Delta(2P_M)_{\frac{3}{2}}^-$	i0.073	i0.088	0.561
$\Delta(4D_S)_{\frac{3}{2}}^+$	-0.036	0.021	0.070
$\Delta(1920)$	-0.040 ± 0.014	0.023 ± 0.017	
$\Delta(4D_S)_{\frac{1}{2}}^+$	--	-0.021	0.035
$\Delta(1910)$	--	0.020 ± 0.010	
$\Delta(4D_S)_{\frac{5}{2}}^+$	0.057	0.013	0.095
$\Delta(1905)$	0.022 ± 0.005	-0.045 ± 0.010	
$\Delta(2P_M)_{\frac{1}{2}}^-$	--	i0.075	0.077

TABLE II: The amplitudes and decay width for $R^+ \rightarrow \pi \Delta$. The suggested values by the PDG are listed in the last column [1].

State	PDG	$A_{3/2}^\pi$	$A_{1/2}^\pi$	Γ [MeV]	Exp. [1]
$N(4P_M)_{\frac{1}{2}}^-$	$N(1650)$	--	i0.501	14.2	0-34
$N(4P_M)_{\frac{5}{2}}^-$	$N(1675)$	-i1.182	-i0.847	43.4	65-90
$N(2D_S)_{\frac{5}{2}}^+$	$N(1680)$	-0.533	0.000	4.0	6-20
$N(2S_M)_{\frac{1}{2}}^+$	$N(1710)$	--	-0.067	0.3	8-40
$N(2D_S)_{\frac{3}{2}}^+$	$N(1720)$	-0.282	-0.208	4.2	

TABLE III: The amplitudes and decay width for $R'^0 \rightarrow R^+ \pi^-$.

Channel	$A_{3/2}^\pi$	$A_{1/2}^\pi$	Γ [MeV]
$N(4P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{1}{2}}^- \pi^-$	--	1.520	29.40
$N(4P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{5}{2}}^- \pi^-$	0.856	1.091	23.46
$N(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{1}{2}}^- \pi^-$	--	1.373	23.99
$N(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{5}{2}}^- \pi^-$	-2.869	-3.134	220.18
$\Delta(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{5}{2}}^- \pi^-$	-1.006	-0.929	13.68
$\Delta(2P_M)_{\frac{3}{2}}^- \rightarrow N(4P_M)_{\frac{1}{2}}^- \pi^-$	--	0.501	2.03

only one coupling constant g_2 for the decay of a state with

spin 3/2 into one with spin 1/2. The analogous can be found for the decay of a state with spin 1/2 into one with spin 3/2.

TABLE IV: The coupling constants f_1 and f_2 for radiative decay and g_1 and g_2 for π^- decay.

Channel	f_1	f_2
$N(^2P_M)\frac{3}{2}^- \rightarrow \gamma n$	-0.938	0.705
$N(^4P_M)\frac{3}{2}^- \rightarrow \gamma n$	0.593	-0.119
Channel	g_1	g_2
$N(^4P_M)\frac{5}{2}^- \rightarrow \Delta^{++}\pi^-$	-0.074	6.664
$N(^4P_M)\frac{1}{2}^- \rightarrow \Delta^{++}\pi^-$	--	0.101
$N(^2P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{5}{2}^-\pi^-$	0.130	6.929
$N(^4P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{1}{2}^-\pi^-$	--	3.733

B. Cross sections and Dalitz plot

With the Lagrangians and the coupling constants obtained in the previous section, the cross section versus the photon-beam energy P_{lab} is calculated with the help of code FOWL in the CERNLIB program. The cross sections from the resonance contribution with the variation of the beam energies P_{lab} is presented in Fig. 3.

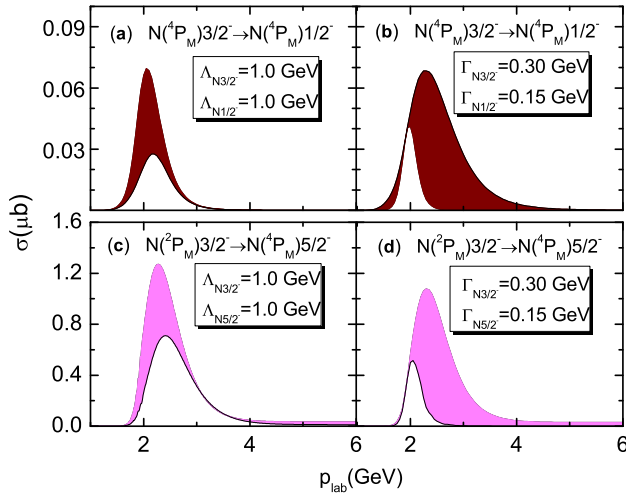


FIG. 3: (Color online) The total cross section for $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ from the resonance contributions versus the photon-beam energy P_{lab} . The panels (a) and (c) are obtained with variation of widths of higher resonance from 0.25 to 0.45 GeV with the cut off $\Lambda = 1.0$ GeV. The panels (b) and (d) with variation of the cut off of higher resonance from 0.7 to 1.3 GeV with width $\Gamma = 0.3$ and 0.15 GeV for the higher and lower resonances, respectively.

The decay widths in Tables I-III suggest that the most important contribution is from the mechanism with decay

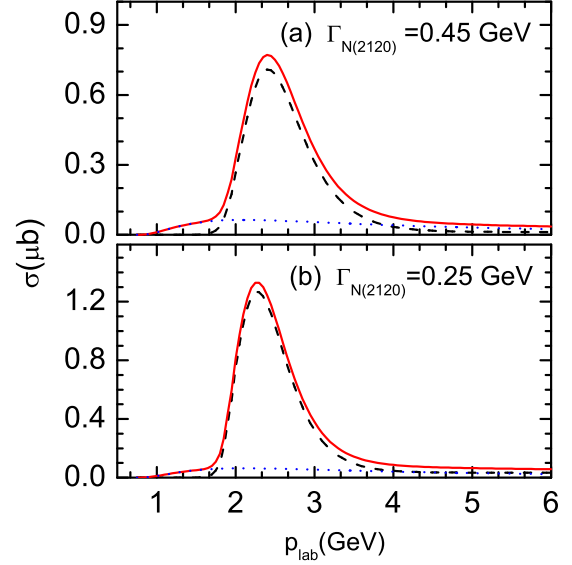


FIG. 4: (Color online) The total cross section for $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ with width $\Gamma_{N(2120)} = 0.45$ and 0.25 GeV and cut off $\Lambda = 1$ GeV. The solid (red), dashed (black) and dotted (blue) lines are for full model, resonance contribution and background contribution.

$N(^2P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{5}{2}^-$. It is confirmed by the numerical results as shown in Fig. 3 where both results with decay $N(^2P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{5}{2}^-$ and results of the second most important mechanism with decay $N(^4P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{1}{2}^-$ are illustrated. The uncertainties arising from the total decay widths and cut offs are also considered. The results with variation of widths from 250 to 450 MeV are shown in Fig. 3(a) and 3(c) and the results with variation of cut off from 0.7 to 1.3 GeV is shown in Fig. 3(b) and 3(d). After these uncertainties are considered, one can find that the contribution from the mechanism with decay $N(^2P_M)\frac{3}{2}^- \rightarrow N(^4P_M)\frac{5}{2}^-$ is more important than these with other cascade decays. In the constituent quark model, the state $N(^2P_M)\frac{3}{2}^-$ corresponds to the $N(2120)$ and the state $N(^4P_M)\frac{5}{2}^-$ corresponds to the $N(1675)$. Hence, one can say that in the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ the contribution from the mechanism with the decay of the $N(2120)$ to the $N(1675)$ is dominant. And the cross section is at order of $1 \mu\text{b}$.

In Fig. 4 the total cross sections with background contribution with $\Lambda = 1.0$ GeV and $\Gamma_{N(2120)} = 0.45$ and 0.25 GeV are presented. The Dalitz plot is also shown in Fig. 5 for reference. The resonance contribution is significant compared with the background.

IV. SUMMARY

In the present work, the possibility to research the decay of the $N(2120)$ to the $N(1675)$ in photoproduction $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ is explored. The decay amplitudes of nucleon res-

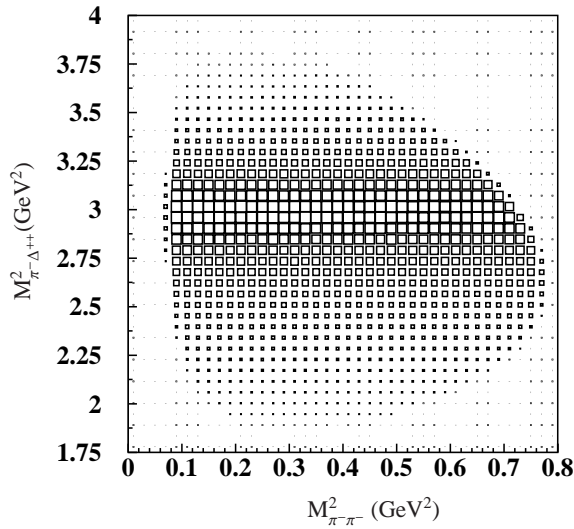


FIG. 5: The Dalitz plot for the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$.

onances are calculated in the constituent quark model. The results suggest that a mechanism with decay of the $N(2120)$ to the $N(1675)$ is dominant in the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$. Other contributions from other nucleon resonances are relatively small and can be neglected.

Numerical calculations for the cross section of the process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ are performed with the effective Lagrangians and the coupling constants obtained from the decay amplitudes. The results confirm that the mechanism with decay of the $N(2120)$ to the $N(1675)$ is dominant and the background contributions are very small. The total cross section of process $\gamma n \rightarrow \pi^- \pi^- \Delta^{++}$ is at order $1\mu\text{b}$, which is large enough to be studied in JLab.

Due to the small background contribution, the peak near 2.1 GeV as shown in Fig. 4 is an obvious signal in experiment to search for the $N(2120)$. According to our calculation, selection of the $N(1675)$ after reconstruction from $\Delta\pi$ will make the signal for $N(2120)$ clearer because of the large decay width of $N(2120) \rightarrow N(1675)\pi$. This interesting exploration of nucleon resonance near 2.1 GeV can be performed in the future experiments of CLAS12@JLab.

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